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Real options analysis for space projects

For the purposes of estimating the value of a project, risk has for simplicity often been treated as spread out evenly over the life of a project. For normal projects these risks can usually be fairly approximated by estimating risk per unit time. This occurs in, for example, the net present value (NPV) formula for estimating the value of a project where a constant interest rate risk premium is used. In a typical space mission, however, risk tends to be concentrated at particular events such as launches, burns, flybies and landings. Just floating out in space is relatively quite low risk, which is why we can fly to Jupiter and Saturn with failure rates not significantly greater than missions to the moon or Mars. All four of the spacecraft that have so far intentionally been flown beyond Saturn -- Pioneers 10 and 11, and Voyagers 1 and 2 -- had many initial glitches. But since passing beyond Saturn they have travelled on for nearly two decades, far beyond Pluto, with no substantial and unexpected failure. The Voyagers continue to send back valuable data on the very edge of the solar system, where the solar wind gives way to the interstellar influence -- more than 80 times as far from the sun as our own earth.

There is a small risk of component failure that tends to obey a Poisson distribution that grows over time. But the risk in even earth-orbiting satellites is dominated by launch and orbit-insertion failures, and other failures at the start of the satellite's lifetime, which are unrelated to the satellite's expected lifetime.

Thus the vast majority of the risk of most space projects does not grow exponentially with their duration, and indeed is usually not closely correlated to their duration in any way. We would thus get an exponentially wrong answer by a line of reasoning that estimated the risk of a generic deep space mission as X%/year, and deduce by plugging that risk into the net present value (NPV) equation that, for example, an 8 year mission is substantially costlier (due to a risk that grows exponentially over time) than a 2 year mission. An example of this fallacy is NPV analysis that assumes a constant risk premium for comparison of futuristic lunar and asteroid mining scenarios. All such papers that I've seen (e.g. this one) fall victim to this fallacy. To use NPV properly we need to account for the risks of particular events in the mission (in the mining scenario primarily launches, burns, and mining operations) to estimate a total risk, and divide that total risk by the duration of the mission to get a risk premium. The risk premium per year for the longer mission will thus probably be substantially lower than for a shorter mission (implying an overall risk slighly higher for the longer mission, all other things being equal).

An even more accurate method for evaluating risk in space projects is called real options analysis. It has changed valuation from the old static NPV model to a dynamic model based on specific risks. One improvement this brings is removing the assumption of constant risk, which we've seen is wildly inappropriate for deep space missions. Another idea real options brings us is that designing a project to postpone choices adds value to the project when there will be better information in the future. A science mission example: if a

About Me

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"Szabo comes out with these essays that leave me in awe." -- Brian Dunbar

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"Like most blogs worth my attention, this blog is updated only infrequently. That is because the authors of blogs worth my attention only post when they have something to say that is true, relevant and not already known by their audience. Most of the human race does not have the skill to know when an idea has these three properties. The skill is particularly rare in the fields of politics and economics, which is why this blog is such a rare and valuable thing." -- Richard Hollerith

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scientific event could occur at either target A or target B, it's best to postpone the choice of target until we know where the event is going to occur. If that's possible, we now have a scientifically more valuable mission.

Orbital planning for deep space missions tends to plan for a fixed mission ahead of time. Real options analysis says that the project gains value if we design in options to change the project's course in the future. For orbital mechanics that means designing the trajectory to allow retargeting at certain windows, even at some cost of delta-v and time. (Whether the tradeoff is worth it can be analyzed using real options mathematics, if we can make comparison estimates of different scientific targets using a common utilitarian scale).

In the context of an Jupiter orbiter swinging by various Jovian moons, such options might include hanging around an interesting moon longer or changing the trajectory to target. The idea is instead of plotting a single trajectory, you plot a tree of trajectories, with various points where the mission controllers can choose trajectory A or trajectory B based on mission opportunies.

A shorthand way to think of real options analys is that the project is modeled as a game tree with each node on the tree representing a choice (i.e. a real option) that can be made by the project managers. The choices are called "real options" because the math is the same as for financial options (game trees, Black-Scholes, etc.) but they represent real-world choices, for example the option of a vineyeard to sell its wine this year or let it age at least another year, the option of a mine to open or close, or expand or shrink its operations, etc.

The orbital planning I've seen tends to plan for a fixed mission ahead of time. Real options analysis says that the project may gain value if we design in options to change the project's course in the future. For orbital mechanics that means designing the trajectory to allow retargeting at certain windows, even at some cost of delta-v and time. (Whether the tradeoffs between delta-v, time, and particular real options are worth it can be analyzed using real options mathematics, if we can compare different scientific targets using a common utilitarian scale).

In the context of the Jovian moons project, such options might include hanging around Europa longer if a volcano is going there (like the one discovered on the similar moon Enceladus) or if some evidence of life is found (or leaving it sooner if not), or changing the trajectory so that the next target is Europa instead Ganymede if a volcano suddenly springs up on Europa, or to Io if an interesting volcano springs up there. The idea is instead of plotting a single trajectory, we plot a tree of trajectories, with various points where the mission controllers can choose trajectory A or trajectory B (sometimes with further options C, D, etc.) based on mission opportunities. Other trajectory options might include hanging around a particular moon for longer or changing the view angle to the target. We may trade off extra delta-v, extra time, or both in order to enable future changes in the trajectory plan.

Here is more on real options analysis. Real options analysis is also quite valuable for the research and developoment phase of a project. Here is a good paper on real options analysis for space mission design. My thanks to Shane Ross and Mark Sonter for their helpful comments on space project evaluation and planning.

UPDATE: This post is featured in the Carnival of Space #22.

Posted by Nick Szabo at 7:01 PM

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